

THE IMPORTANCE OF STRUCTURE  
IN ARCHITECTURAL DESIGN

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## PREFACE

Architectural design and structural engineering are complementary fields in the study of architecture. The architect and the engineer, in order that each may take his rightful place in the creative art of architecture, must acquire a knowledge of his own field plus an understanding of the other's field. The engineer, beyond structural theories and engineering computations, must be sensitive to form; and the architect likewise to structure. This will provide essential mutual understanding of the principles and problems which govern each other's work.

My academic background is in the field of civil engineering and due to my interest in building structures I was convinced to undertake this related study of structure and architecture. This report is a part of my effort made toward an understanding of the role of structure in architecture.

I am indebted to many people: to Professor Emil C. Fischer and Professor Harold J. Miller, both from Kansas State University, who gave early guidance, stimulation and encouragement to my interest in the field of architecture; to Marshall and Brown, architects and engineers of Kansas City, Missouri, for their generous assistance in making available plans and photographs of their projects, and to Marilyn Adams who typed this report. Appreciations are also due to Miss Mary Hodges and my wife for their help at various stages of the report.

## INTRODUCTION

Today, the essential aim in the construction of a building remains very much the same that it was when the first crude shelter was built. However, the actual problem of building has gradually become more complex; and increased complexity has brought about greater participation of science and technology in the architectural design.

The scientific progress and the development of technological principles has influenced the development of buildings. The Egyptian architect (3000 B.C. --1st century A.D.) was limited by the fact that he had to use massive walls and closely spaced columns with lintels supporting a stone roof, as the method of construction (Plate I, Fig. 1). Lack of wood and abundance of stone and sun dried bricks dictated his main building materials. Spans were therefore limited by stone material. The result was constantly repeated rectangular forms of massive block walls and columns which gave a look of simplicity and solidity but denied the design of large spaces uninterrupted by supports.

The Greeks (650--30 B. C.) also used post and beam construction which basically was similar to the construction employed by the Egyptians. The use of a trussed wooden roof with sloping rafters permitted slightly greater spans. The exterior, however, was a pedimented roof supported on a series of columns and walls (Plate I, Fig. 2). The stone lintel and column system used during these periods was strong in compression but

weak in tension (Plate I, Fig. 3).

The Romans (300 B. C. --365 A. D.) demonstrated a great construction ability by understanding the structural principles involved in the construction of the true arch, vaults, dome and roof truss, as well as use of concrete. The Roman civilization, with its greater stress on social life, the selective form of government and desire for glorification of its rule, required large uninterrupted spaces for public buildings (such as theatres, bathhouses, basilicas, assembly halls, etc.). The true arch principle, continued from the Etruscan period, made possible the larger spans, which in turn generated a variety of structural forms (Plate I, Fig. 4; Plate II, Fig. 1, 2, 3).

The horizontal projection of the arch formed a barrel vault, which could be used to cover wide rectangular areas (Plate I, Fig. 4), whereas the cross vaults (which were formed by the intersecting of two barrel vaults) permitted more flexible development of space (Plate II, Fig. 1). Hemispherical domes were developed over a circular plan (Plate II, Fig. 2) to permit assembly of large groups without being hindered by supports.

The structural principle which permitted utmost flexibility in the use of the dome was developed in Byzantine architecture (330 A. D. -- 1453 A. D.). "Pendentives" (spherical triangles) were developed (Plate II, Fig. 4) to permit a dome to be erected on a square bay. This was one of the main contributions of the Byzantine civilization. This type of construction permitted the dome to become a predominant feature.

During "Romanesque" times (7th century A. D. --12th century A. D.), there was a need to develop techniques to span increasingly larger rectangular spaces as the Christian church developed in the West. These areas also needed a fire-resistant roof which eliminated wood the roof truss for construction. Roman cross vaults were heavy and difficult to construct, and were gradually replaced by "rib and panel" vaulting. This new method of construction allowed a framework of ribs to be erected first and later filled in with panels (consisting of beds of mortar laid in with dressed stones of comparatively small size) (Plate III, Figs. 1, 2) which gave a modular construction.

The use of semicircular arches for ribs, usually limited spans to square bays. The diagonal rib, starting from the same level and having the largest span, rose to a greater height than the transverse and longitudinal ribs. This gave an uneven effect by awkward waving of the ribs. This construction also relied on heavy walls to resist thrust and allowed only small window openings in the walls.

Around the twelfth century, the church ritual was highly developed and the needs for loftiness and delicacy were urgent in church architecture. Gothic architecture (1200 A. D. --1600 A. D.) satisfied this need by developing a pointed arch to sustain the ribbed vault construction (Plate III, Fig. 3). This marvelous architectural form was developed from the heavy, rather clumsy, Romanesque.

A Gothic structure consisted of a skeleton of piers, buttresses, arches and ribbed vaulting, all held in equilibrium by the combination of vertical and oblique forces neutralizing each other. Walls practically disappeared. A church became a glass house. The use of the pointed arch is regarded as the chief visible characteristic of Gothic architecture. Pointed arches made possible the equalization of the vertexes (regardless of the span) and the crown of all arches could now be at the same height. Gothic architects understood dynamic construction. This structural technique illustrates the highest development of arcuated construction.

About the fifteenth century civilization in western Europe changed completely. Medieval man turned his back on Gothic society and began to consider his great classical past. Renaissance architecture (1500 A. D. -- 1900 A. D.) reflected the grand construction of spatial forms and scale which were needed to build for the nationalistic attitudes of developing countries. Instead of developing Gothic form, Renaissance architecture reverted to Roman. The Gothic pointed arches and ribbed vaults were abandoned for the semicircular Roman arch and dome. The domical vault and dome on pendentives were developed further and used in a variety of old as well as new ways. Renaissance architects raised the dome on a drum to accommodate windows and to give this motif a more dominant appearance. Domes were composed of double or triple shells; the outside dome was usually crowned with a lantern (Plate III, Fig. 4).



The objective analysis of the historical development of architectural form shows (among other influences such as social, religious and climatic) that both building materials and the progressive knowledge of construction methods played important parts. The post and lintel or beam construction generated predominantly rectangular architectural forms of limited span in Egyptian and Greek architecture. The adoption and development of the arch principle by the Etruscans and Romans permitted the development of larger spaces. These evolved into the pointed arch and vault with strong ribs and exterior bracing during later Gothic times. These structural principles (post and beam, arch, vault, and dome) were developed to a very high degree of efficiency (using bricks and stone) by these former civilizations but until the mid-nineteenth century, building materials had not changed; only techniques developed. Only after the development of steel, the elevator and the pump, could the architect and engineer answer the economic demands of our modern civilization for taller structures.

Structure is a major ingredient of architectural form and is one of the important aspects of architectural design. In this paper the importance of structure in the architectural design is discussed with a particular emphasis on its relationship to and as a determinant of aesthetic form, which brings up such questions as: What is architecture, and, What is the architectural design process? The earlier part of the paper is devoted to consideration of basic purposes and classifications of structural

systems according to (1) the methods of constructions, and (2) the relationship of internal space to their resultant aesthetic form.

With this information as a background, the importance of structure in the architectural design is discussed mainly through the aesthetic influences and the dominant factors which influence the selection of structural systems. There are problems which arise in the integration of structure and aesthetic form and these are examined through the analysis of a particular example.

The proper integration of functions of work and structural functions can lead the way to aesthetic structural form expression through integrated structure.

## THE ARCHITECTURAL DESIGN PROCESS

"For work or play man needs shelter. We call them buildings and the art that elaborates them is Architecture."<sup>1</sup> The process of elaborating shelter into architecture is the architectural design process. It is essential to examine what is architecture before reviewing the design process.

### What is Architecture

Architect Mies Van Der Rohe says, "Architecture begins when you put two bricks together carefully." Architecture is a complex final product of art and science. It starts with the design process and takes final shape through the construction of a building where everything is integrated and interwoven as one.

Architecture has revealed and represented the civilization in which it was created. Each period had its own science, religion and philosophy, each of which demanded that their story be told in stones and bricks. Whatever may be the influences of periods, the true architecture at all times shows the proper integration of the three aspects which Roman Vitruvius first listed, and Sir Henry Wotton called commodity, firmness and delight.

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<sup>1</sup>Grillo, Paul Jacques, What is Design? Paul Theobald and Company, publisher, Chicago. Pg. 36.

Commodity represents function. The basic function of a structure is to provide shelter during various human activities. Auditoriums must be so constructed that every seat will give an unobstructed view of the stage, and no echoes or undue reverberations will destroy the sound. A large uninterrupted space is required for a field house. Houses must have privacy and convenience. All these and other functional uses demand that the interior space should be arranged in a particular way.

Thus each type of interior space has its own implications as to the structural system best suited to enclose it. That is why the character of structure identifies the building's purpose. As a result the bank would have the physiognomy of a bank, the church would be recognized as such, but the billiard room and the chapel would not wear the same uniform of columns and pediments.

Structure that encloses the space should be firm and stable. It must be statically logical. Each structural element should perform its function of load carrying, and structural system should show the sequences in which loads are transmitted to safe places.

"The aesthetic stimulation of architecture rarely appears as the deliberate aim of creative work."<sup>2</sup>

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<sup>2</sup>Belluschi, Pieho. The Northwest Architecture of Pieho.  
Belluschi, F. W. Dodge Corporation, New York: 1953.

In the work of true architecture, the aesthetic is often an outcome of the process of integration of functions, structure and other aspects of architecture, such as scale, mass, space, detail, etc.

If the structure is good, is it necessarily architecture? I don't think so. If the external appearance of the building is beautiful, is it good architecture? It might or might not be. In the great works of architecture all these factors (commodity, firmness and delight) are made absolutely one, giving reality, seriousness and aesthetic richness. Architecture is not only built beautifully, but also it must be strong, durable and efficient; it should serve all the practical purposes for which it is built.

### An Architectural Design Process

The architectural design process can more generally be called the process of integration of art and science devoted to the creation of a total environment suitable to a man. The design process starts with a preliminary work of analysis and is completed with a final product of imaginative synthesis in which different elements of buildings are co-ordinated, balanced and integrated.

The architectural design process can be divided into two stages: preliminary design and final design process.

The preliminary design process starts with the presence of a client in an architect's office. The client tells his needs, intended function in the building and amount of money he would like to invest in the project. The

architect then starts various studies about the project which are outlined as follows:

I. Background data.

- A. Client and his views about the project.
- B. Location of building.

II. Description of Functional Requirements.

- A. How does the client want the building to work:
- B. How does the building serve the needs of the community, if the building is to be a public or business place?

III. Environmental Factors.

A. Site problems.

- 1. Site selection (if not already selected by the client); building location and how it fits with the community pattern.
- 2. Site uses and development.
  - a) Existing and new topographic features.
  - b) Aesthetic landscaping.
- 3. Circulation.
  - a) Vehicular and pedestrian access.
  - b) Service access.
  - c) Relationship between functional areas in floor plans.

B. Climate problems and considerations.

IV. Technical Aspects.

A. System of construction.

- 1. Structural form.
- 2. System of enclosure.

B. Use of Materials.

1. Character, expression and durability of materials.

C. Acoustics.

1. Interior.
2. Exterior.

D. Mechanical equipment.

1. Lighting (artificial and natural).
2. Heating, ventilation and airconditioning (if any).

V. Aesthetics in Architecture.

A. Analysis of composition.

1. Space, form and materials.

B. Analysis of relative expression.

1. Construction, use, scale and symbolism.

After considering all these factors, the architect prepares preliminary plans for the building project, to get the client's approval for overall design.

If the client approves the preliminary design, the final design process begins. The architect and his engineering consultants then try to solve the problems by weighing and balancing different factors involved in the process. At this stage, the general feeling is that the problem solving in the design process should be used to get more acquainted with the project objectively, rather than to accept it as the ultimate solution. For

"Architecture is more than a solution of these problems."<sup>1</sup>

With much deeper understanding of the problem at hand all the personalities concerned with the architectural design process - engineering consultants and the architect as a creative co-ordinator - may have more opportunities for creative thinking. In this way the most suitable solution may naturally emerge, which is capable of both architectural expression and structural logic.

#### Influence of Structure in the Architectural Design Process

In architectural design, one of the basic roles of structure is to help put forth the dream of the architect in reality. Structure, then, is a means and not the end of subjective expression. "Structural expression along," says Edgralo Contini, "however brilliant, however imaginative, is not adequate or self sufficient as an expression of architecture."<sup>2</sup>

In the design process, the architect analyzes different architectural elements with respect to surroundings, functional requirements and climatic conditions. Some of these elements are not only purely architectural but they greatly influence the structural concept involved in the particular project.

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<sup>1</sup>The role of the consulting engineer in the design process. Progressive Architecture, Jan., 1952. Pg. 128.

<sup>2</sup>Contini, Edgralo, Design and Structure, Progressive Architecture, Feb., 1958. Pg. 152.



Selection of materials is one of them. Durability, availability and economy do play important parts in the choice of materials. However, other qualities such as the craftsman feeling of materials and their relationship in expression govern an architect's selection. These contribute to texture and the effect of light and shade. But the choice of materials, if not used as purely architectural materials, is greatly influenced by technical or structural properties.

In multi-story skeleton frame, the column sizes become a governing factor after certain stories, demanding the use of steel. However, in a building of average height, the dead weight will influence selection of materials although there are many other architectural influences to be considered.<sup>1</sup>

The monolithic nature and the flexibility of concrete are used in thin shell structures to reduce the bulk of material; the result is a "free flow" of stresses which gives an unquestionable pleasing appearance as can be seen in the works of Pier Luigi Nervi.

Structural materials can be divided into two classes: those that take tension, and those which stand compression effectively. Types of structures and the manner of collecting the transferring loads then reveal a suitable structural system. This in turn indicates whether tensile or compressive (or both) materials will be selected.

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<sup>1</sup> These considerations are architectural influences which are beyond the scope of this report, such as special effect desired by the architect.

The structural elements are sometimes exposed for architectural expression. This requires a special consideration with respect to a material's technical properties and texture in terms of long time exposure.

The essential purpose of structure is to transform external loads into internal stresses and to transmit these, distributed along the structural members, to convenient locations, usually to firm ground. The efficiency with which this can be accomplished depends entirely upon the type of structure, its properties and nature of its support. In the architectural design process an architect studies the different function, i.e. through a series of plans and elevations. He then broadens the bases of his analysis so as to integrate different architectural elements<sup>1</sup> and expresses his subjective idea.

Fred Severud, an American engineer, has this to say:

The engineer should not enter into the architectural design process until the architect completes the preliminary design and puts forth the structural idea.<sup>2</sup>

It is at this stage that structural consideration should be given by the engineering consultant to the architectural idea; because the structural engineer can grasp the concept of what the architect is trying to achieve.

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<sup>1</sup> Such elements as unity, variety, balance rhythm, proportion, harmony, scale, etc.; discussion of these elements is beyond the scope of this report.

<sup>2</sup> The Architectural Forum, "Building U.S.A." New York, McGraw-Hill, 1957.

Some engineers belong to the school of thought that an architect should consult the engineer from the early design stages in order to avoid the extra work and repetition that may be caused by illogical structural solution. On the other hand, there is a danger of overemphasizing the structural considerations if the structural engineer enters into early design stages.

Structural influences in architectural design also depend upon the type of architecture considered. For example, Ranchamp, by Le Corbusier, is one such building. It is shown in Plate VI. This building has only one structural requirement: to make possible the expression desired by the architect. There are other types of buildings in which satisfaction of structural requirements are of major importance. The functional requirements imposed on such buildings demand specific structural solutions. In other words, the building incorporates ideas, the solutions of which rest primarily on the fulfillment of structural requirements.

The role of structure in the architectural design process varies with building types. "A purely structural solution," says Gunhord Aestins Oravas, "rarely, however, meets the functional requirements of the best architectural solution. So that a satisfactory balance must always be struck between the two alternatives: the best architectural design and the best structural design."<sup>1</sup>

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<sup>1</sup>Gunhord, Aestins Oravas, "Thin Shells" Engineering Fitness and Architectural Form, Architectural Record. March, 1960, Part I.

### Principle Involved in the Design Process

Structural science is making such headway in recent years that the architect, structural engineer and other technical consultants are faced with numerous varieties of structural systems from which to choose. Yet choice is not free; each type of system has its own implications as to the type of interior space enclosed and the special material best suited for its construction. Each type of structural system has its own characteristic shapes that help determine the appearance. The sound selection of a system for any building project is governed by stability and suitability of system to create the form corresponding to the functions which the architectural elements must discharge.

What are some academic check points? These will be discussed as principles involved in the design process.

The first principle can be called "planning for use". All activities for which the building is planned should really fit under the selected structural system.

Secondly, does the structure have visual quality that is pleasing? With the proper engineering the building would acquire a certain visual quality that is quite important.

The third one, does the structural system really make use of the materials applied? For example, steel is very strong in tension. Is it then used in tension or in compression? In other words, does material bear any relationship to the structural system used?

Fourth, "structural analysis": is the material pushed where the stresses require it, or did more material have to be added in order to follow the stresses?

The next one is called "material technology". Are these materials, for this particular dream of the architect, really available? In other words, structure should not only support loads; it should furnish the aesthetic appeal.

Is the geometry of a structure utilized in resisting loads? Structure should be designed by utilizing the characteristics of the entire system rather than individual members, thus leaving to chance the interaction between them (individual members).

Selection of a structural system is ultimately the engineer's responsibility, but it is necessary for the architect to get acquainted with some of the principles involved in design process in order to come up with a comprehensive preliminary design.

These six principles, stated above, are mostly academic. However, architects and engineers who have devoted their lives to pursuit of creative design offer more principles; and these are best stated in their own words:

The architect Pieho Belluschi says:

The architectural dictionary has so fascinated some designers that they found themselves using its forms even before the function of building was established.

Architectural forms which are not born of logic, study and deep understanding of the peculiar problem at hand, but come out of preconceived aesthetic theories, will always be in danger of becoming artificial or just fashionable.<sup>1</sup>

The engineer, Pier Luigi Nervi:

In examining and deciding upon the most suitable structural scheme, the most varied solution gradually emerges. After elimination of that which is irrelevant and unimportant and strictly adopting structural form to function, the most aesthetic solution may emerge.<sup>2</sup>

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<sup>1</sup> Belluschi Pieho, "The Northwest Architecture of New York", 1952. Edited by Jo Stubbebine, An Architectural Record Book, F. W. Dodge Corporation, New York, 1953.

<sup>2</sup> Nervi Pier Luigi, "The Place of Structure in Architecture", Architectural Record, July, 1956. Pg. 189.

## THE PLACE OF STRUCTURE IN DESIGN PROCESS

Influence of structure in the architectural design process if previously discussed as to when it may enter the process. In this chapter the basic purposes of structure are examined and their systems are classified according to their ability of enclosing interior spaces. With this information the comprehensive use of structure to express aesthetic forms is considered.

### Purpose of Structure

Structures are used as facilities for enclosing space. When a primitive man hung skins on the branches of a tree, he first used its structure to enclose space.

Today this idea has reached the climax where steel and glass is used to enclose huge spaces. However, the essential purpose of structure is to transform external load into internal stresses and to transmit these, distributed along the structural members, to convenient location, usually to firm ground. In a single story building, with a large span, emphasis is given on load collection, while in the multi-story building load transfer is emphasized. These are the two main purposes of structure. However, the structures are often exploited for architectural expression by exposing different structural elements.

## Classification of Structural Systems

Structural systems can be grouped in numerous ways according to their different characteristics. Felix Condela<sup>1</sup> classified structures, considering the manner in which external loads are transmitted, into two basic classes: passive structures and active structures. Passive structures conduct loads directly without changing their course, like bearing walls and columns which are merely elements interpassed between the loads and ground. Active structures are capable of changing the direction of loads and forcing them to move through the structure enclosing a certain space.

Construction methods have a profound effect on both the arrangement and the appearance of buildings. Structural systems can be classified in three main groups according to methods of construction. They are the post or wall and lintel; the arch or vault, and the truss construction. These terms are self explanatory.

Still, there is another way to group the structures systems, namely bearing wall and framed construction. In bearing wall structures the walls that keep out the weather or divide the various areas of the plan also support the entire weight of the floors and roofs. In framed construction the walls are frequently mere protective or dividing screens carrying no weight

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<sup>1</sup>Felix Condela, "Stereo Structures", Progressive Architecture, June, 1954. Pg. 84.



except their own; all the major weight of floor and roof, and sometimes even the walls themselves, is born by a skeleton frame specially designed to carry them.

The chief material also can be taken as the basis of classification. The structures can be designated as either steel, wood, concrete or masonry.

In this paper, for sake of simplicity and convenience from the architectural viewpoint, structural systems will be divided into three major groups according to mode of construction and the relationship of their external form and internal space. These are solid, skeleton and surface construction. Solid bodies, slender members and stressed surfaces form the three basic elements of building structure.

Building construction in which enclosed space is surrounded by solid mass is called solid construction. Caves can be considered its most primitive form.

Egyptian pyramids and Indian temples carved out of solid rock (Plate V) are good examples of solid construction. Present day masonry bearing wall construction is also included in the same classification. In solid construction the external form is independent of the internal space. In other words, internal space may not follow the boundary of external surface.

On the other hand, a frame work of slender members, whose cross-sections are small compared to the structure as a whole, is used in skeleton

construction. The exterior walls and panels are used only as space limiting elements. The tent is the primitive form of the skeleton construction.

In its most developed form it can be seen in the steel skeletons of present day skyscrapers. Struts, columns and beams are the basic elements here. In skeleton construction external form and internal space coincide through separation of load bearing and space limiting elements.

The third classification of structural systems is surface construction. Unlike solid or skeleton construction, surface construction uses surface as basic elements. Only in recent times due to advance of technology are materials available which make possible the surface construction. The box-frame structures (Plate VI) and thin shell structures belong to surface categories. In surface construction the external form coincides with internal space and internal form.

However, a majority of domes built in the past, due to their bulk, can be classified as solid construction.

The differences between these three types of structural classification are not only due to manner of construction or limiting spaces, but also the way in which external forces are carried to the supports.

Solid construction relies on a heavy homogeneous wall mass in which the compressive stresses are uniformly distributed and carried to firm ground.

In skeleton construction the slender light frame work of rigid members channels the forces into single elements and then on to the firm ground.

The shell, by virtue of the curvature of its surface, transmits force (all in the contour of the surface) chiefly by direct stresses of tension, compression and shear rather than by bending as in the flat plates. Such stress characteristics of shell are called membrane stresses.

The load-carrying behavior of box-frame construction is essentially the same as skeleton frame except for the buckling tendency of panels due to plate action which has to be specially provided for.

Furthermore, in solid construction the applied loads are transmitted only in one dimension. In skeleton construction two-dimensional structural elements (those transmitting loads in two different directions in the same plane) can be utilized. In shell construction, by means of appropriate structural shape, forces can be transmitted in a three-dimensional concept, deriving the maximum strength from the material employed.

The division between solid, skeleton and surface construction leads to difficulties. The majority of buildings do not belong exclusively to any one form. More frequently elements from several types of construction are combined in one building.

### Factors in Selecting Structural System

Functions to be carried out in a building determine the length, breadth and height of space required, and their arrangements to facilitate circulation. Space is not comprehensible in itself, but has first to be created by the limited surfaces.

If one or more of the limiting surfaces is missing, the eye is able to supplement them. It is also possible for the limitation to consist of individual elements which are added visually in perspective to a limiting wall, a boundary surface,

says Fred Angerer and he goes on:

One also can distinguish between a genuine space limited on all sides by planes and optical space. One of the chief problems of building has always been how to erect such space defining planes.<sup>1</sup>

As already examined in a previous chapter, this bears important relationship in inner space and external form. To grasp the internal space, to know how to see it, is then the key to understanding the building.

First step in selecting structural system then lies in the critical examination of the functions of the work, the areas of its main subdivisions, and the vertical and horizontal functional connections required between the various part of the work. This understanding may clarify the complex situation leading to the great number of possible solutions.

The freedom of selecting structural forms also depends upon the dimensions<sup>2</sup> of the building and on the pattern of loading of different functional units. This then involves technical aspects of structure.

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<sup>1</sup> Angerer, Fred. *Surface Structure in Buildings*, Reinhold Publishing Corporation. New York, N. Y., 1961.

<sup>2</sup> Dimensions of building here refer to dimension of different areas of main subdivisions of the building.

Many of the leading men in the field of architecture emphasize that an honest expression of a structural scheme will be architecturally eloquent.

They have this to say:

Nervi:

It may be advisable to consider the efficiency of the two separate phases of any architectural achievement. The creative efficiency which decides the principal characteristics of the work, and the efficiency of its realization, which defines dimensions and structural characteristics in detail.<sup>1</sup>

I have in mind the danger of fake structuralism, that is, of a structuralism which instead of being born of the natural materialization of structural construction requirements, originate in a presumed formal structuralism which may not correspond at all to the statical reality of the problem. In other words, I am referring to the danger of structures being generated by the exterior appearance rather than by the inner essence of the statical problem.<sup>2</sup>

The study of the architectural works of the past should consist in the critical examination of their functional and structural solutions and of the relation between these and form, in order to show that form is a consequence and not a determinant of functional and structural needs.<sup>3</sup>

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<sup>1</sup> Nervi, Pier Luigi, *Structures*, translated by Giuseppina and Mario Salvadori.

<sup>2</sup> Nervi, Pier Luigi, *The Place of Structure in Architecture*, *Architectural Record*, July, 1956. Pg. 189.

<sup>3</sup> Nervi, Pier Luigi, *Structures*, translated by Giuseppina and Mario Salvadori.

Van Der Rohe Mies:

I believe in structural architecture. Gothic was structural. Most good buildings were structural. Structure is a spiritual notion, a clear principle, not just something you nail together.<sup>1</sup>

Felix Candela:

Bending stresses must be avoided by judicious selection of appropriate shapes. In other words, the structural function depends essentially on the form. But not having the liberty to select form on a structural basis - the shape of building being determined by other considerations - it is most unlikely that correct structures can originate through this design procedure.<sup>2</sup>

#### Relationship of Structure and Aesthetic Form

In the previous chapters, relationship of interior space and structural systems was discussed with particular emphasis on their suitability to functional need. The different types of structural systems through their construction methods (namely solid, skeleton and surface) were examined to see how they affect the architectural form. Technical limitations of structural systems were also considered but as Hardy Cross said, "We must always remember that what we want is a structure not merely an analysis."<sup>3</sup>

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<sup>1</sup>Van Der Rohe, Mies, Views Compared by Leading Architects, Jones, Architectural Forum, September, 1956. Pg. 148.

<sup>2</sup>Candela, Felix, Stereo Structures, Progressive Architecture, June, 1954. Pg. 84.

<sup>3</sup>Ibid.

This prompts us to study two things: how the above mentioned phases of structural design supplement each other, and the capacity to feel a structure in an intuitive way as a concept, both of which represents the indispensable bases for structural design. In this light, then, the relationship of structure and aesthetic form will be investigated.

Architectural design, the creation of environment, is ultimately the responsibility of the architect and it is very seldom that structure alone is adequate to create environment or even to express architectural sensitivity with some exceptions such as Maillart's bridges. One such bridge is shown in Plate VII. Note its extremely sensitive responses to the natural environment in terms of form and scale; the response that is revealing of Maillart's very rare twin gifts of design sensitivity and structural inventiveness.

To acquire the critical sensitivity necessary to exercise choice or rejection of structural form, the understanding of structure as an essential of architectural form and that the ultimate form should respond to express orderly relationship with purpose or function, should be gained. There are a number of different criteria to be considered for analyzing the integration of architectural form and structure for their aesthetic expression.

Balance and harmony are two criteria. Once a structural form is selected, the question should be raised whether or not its relationship to the building as a whole and its surroundings is a conquest of total aesthetic balance. Plate VIII shows Nervi's Exhibition Hall in Turin, Italy. The

continuous corrugated arches are brought down onto point supports in a rather remarkable way. This imaginative roof enclosure in an otherwise conventional and uninspired building, makes it aesthetically satisfying.

A second criterion is purpose. The selection of a structural form should be consistent with the use and purpose to which the building is to be dedicated. The use of appropriate structural form to suit the purpose exactly may be a source of aesthetic stimulation.

A third element is scale. Interesting and clever forms can certainly be developed for the enclosure of any space. But the response to a sense of propriety suggests that for the covering of relatively short spans the effort in development of new forms is occasionally wasted and meaningless. For example, the hyperbolic paraboloid, delicately balanced on its two points of support, holds a superb design potential for covering aeroplane hangers or major open shelter. On the other hand, its use would be inappropriate to a house that shelters a plan of otherwise relatively conventional nature (which impairs the viewing of the fully expressed form by partitioning and separations and in which the varied and slight slopes of the ceilings fail to express the basic concept of the design). The architectural form which is not born of logic and deep understanding of the particular problem at hand but which come out of exterior appearance "will always be in danger of becoming artificial and just fashionable."<sup>1</sup>

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<sup>1</sup>Belluschi, op. cit.



The fourth criterion, and perhaps the most difficult to define, is the one of design consistency. When forms derived from structure are adopted, the problem of relating them to each other and to the various elements of the building, itself remains to be solved in terms of total architectural consistency, for lack of which no amount of imaginative or technical brilliance can provide absolution.

The Virgin Milagrosa, a church of fantastic sensitivity (see Plate IX) is a combination of vaults with a main nave and lateral chapels visible on the exterior, but the effect inside is far from regular or customary. It gives more dramatically visible form than any other comparable structure to the concept of a warped slab, a remarkable tribute to the way in which a spectacular technical achievement has been subordinated to an aesthetic end.<sup>1</sup>

It will be appropriate to close this chapter with the remark of a great architect-engineer, Pier Luigi Nervi: "My belief in the inherent aesthetic force of a good structural solution was never shaken."<sup>2</sup>

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<sup>1</sup> Boyd Robin, Engineering of Excitement, Architectural Review, Nov., 1958. Pg. 295.

<sup>2</sup> Nervi, Pier Luigi, The Works of Pier Nervi Luigi. Preface.

## AESTHETIC STRUCTURAL FORM EXPRESSION

The structural functions, when integrated with architectural form with all portions mutually interacting to achieve total expression of composite action, produce what is called an integrated structure. In this class of structure the stress flows are continuous. Based on a background of knowledge of structural theories, coupled with experience, intuition leads the way to synthesize their complex structural behavior. However, quantitative precision is generally not possible by intuition so that their analysis should be substantiated by rational techniques. This often offers the most difficulties due to statically indeterminate nature and nonrectangular cross-sections of structural elements which are so frequently inherent in integrated structures.

In planning a building the structural functions, the functions work and architectural form when conceived as a whole bring up a technical solution of greatest aesthetic value. We will call it aesthetic structural form expression. Some examples are the Johnson War Tower by Frank Lloyd Wright; Air Force Hanger (Rome, Italy) by Pier Luigi Nervi; Botanical Garden Climatron (St. Louis, Missouri) and Restaurant Xochimileo (Mexico) by Felix Candella.

This chapter is intended primarily to discuss the problems in integration of structure and form with the help of an example. The building chosen as an example is Home State Bank, facility at Kansas City, Kansas.

It was designed by Marshall and Brown, Architects and Engineers of Kansas City.

The structure is a conventional three-story building designed to carry out the usual functions of a medium sized bank. Main functional areas are safe deposit and storage vaults, lunch room, mechanical equipment, bookkeeping, secretarial, conference area, offices and main banking lobby. It will be assumed<sup>1</sup> that this arrangement of the areas will allow the functions in the building to proceed effectively (Plates XIII, XIV, XV).

The architect, by grouping individual space units, developed a predominantly rectangular box type architectural form (Plates X and XI). The clever horizontal and vertical arrangement of masses, accented with vertical and horizontal bands of contrasting white stone with dark face brick, has produced a pleasing exterior. The aesthetics of the mass relationship has been brought about by slight cantilevering of the upper two stories from the ground floor. The whole form clearly reveals the main materials as tensile.

Structurally (as it is built) it is predominantly the skeleton type of construction using steel as its main structural material (Plates XVI, XVII and XVIII). The steel skeleton frame is hidden from view by a facade of masonry and opaque panels. Vertical masonry pilasters on east and west

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<sup>1</sup>Discussion of architectural design is beyond the scope of this report except when it directly clashed with structural functions.

sides of the building (Plate XI), which are nonstructural in character, are only used to give vertical accent. However, they create an illusion of supporting the main mass of the building by giving the mass the appearance of framing into their sides. The concept is much in contrast to both the material properties and the massing effect so delicately expressed by cantilevered form.

The front canopy (see Plate X) consists of channel shaped one-way concrete slabs, spanned between cantilevered concrete beams which are framed into column sides. These seem to create the effect of vaulting. This particular structural expression does not suit the material used.

However, only cantilevered construction of this canopy would be more consistent with the nature of material used.

The structural frame in this building is covered by architectural materials. It matters little in exterior appearance whether concrete or steel is used as a main structural material. The complexity of construction caused by steel framing often resolves to using concrete for framing certain areas (Plate XVI and XVII). The concept of a two-way concrete solid slab or a two-way concrete ribs slab might be used with advantage in architectural expression and structural functions in this particular case.

The building has an overall pleasing appearance and has taken the advantage of sloping terrain rather remarkably (Plate XI).

5. Relationship of internal space to external form, dimensions and pattern of loading of different functional areas, and the honest structural expression are the factors an engineer should incorporate in his overall analysis of structure.

6. Investigation of the relationship of structure and its aesthetic form reveals that the criteria - balance and harmony, purpose of building, scale and its relationship to structural form, and design consistency - are of particular importance.

Integration of structural functions with architectural form elevates the technical solution to its greatest aesthetic value.

## PLATE I

Figure 1: Egyptian method of construction. Use of massive walls and closely spaced column with lintel supporting stone roof is shown in section.

Figure 2: Greek Temple showing pedimented roof supported on series of columns and walls.

Figure 3: Stone lintel and column system showing weakness of stone in tensile traces.

Figure 4: Roman Barrel vault formed by horizontal projection of arch.

## PLATE I

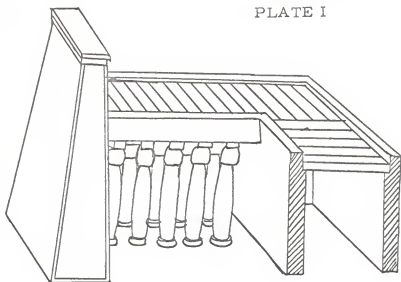


Fig. 1

Fig. 2

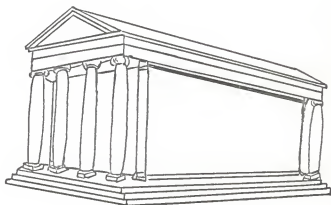


Fig. 3

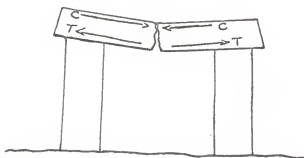
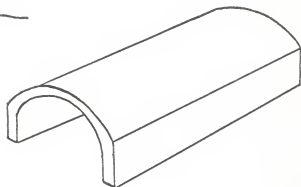


Fig. 4



## PLATE II

Figure 1: Roman cross vaults formed by intersecting of two barrel vaults which are used in Roman bath houses.

Figure 2: Section through the Pantheon showing construction of domes.

Figure 3: Roman aquaducts showing use of true arch principle which unable to span slightly greater spans than the lintels. The arrows show the manner in which the loads are carried to supports.

Figure 4: Showing construction of Pendentives (of spherical triangles) which is used to erect a dome on square bay - development of Byzantine Architects.



## PLATE II

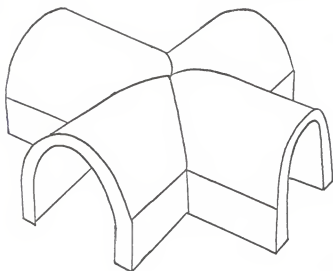


Fig. 1

Fig. 2

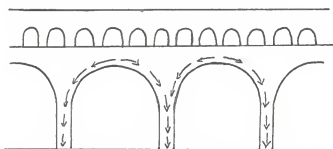
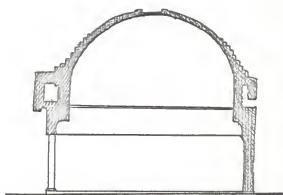
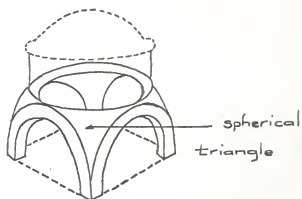


Fig. 3

Fig. 4



### PLATE III

- Figure 1: Perspective view of "rib and panel" vaulting showing diagonal, transverse and longitudinal ribs and their awkward waving which gave uneven effect - development of "Romanesque".
- Figure 2: Plan showing rib and panel vaults. Notice the two square aisle bays to one nave bay.
- Figure 3: Perspective view showing use of Gothic pointed arches to sustain the ribbed vault construction.
- Figure 4: St. Peter's Dome (Renaissance) showing the lantern, the dome and the drum.

## PLATE III

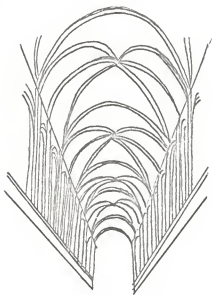


Fig. 1

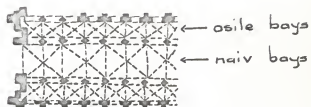


Fig. 2



Fig. 3

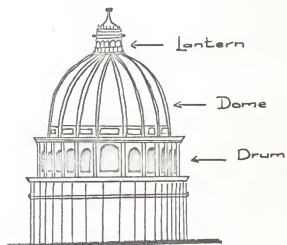


Fig. 4

PLATE IV

Ranchamp, by Le Corbusier

Figure 1: Exterior

Figure 2: Interior view, main structural purpose is to make possible the expression desired by the architect.

## PLATE IV



Fig. 2



Fig. 1

PLATE V

Lingaraga Temple

Section showing the solid construction where  
external surface is independent of the internal  
space.

## PLATE V



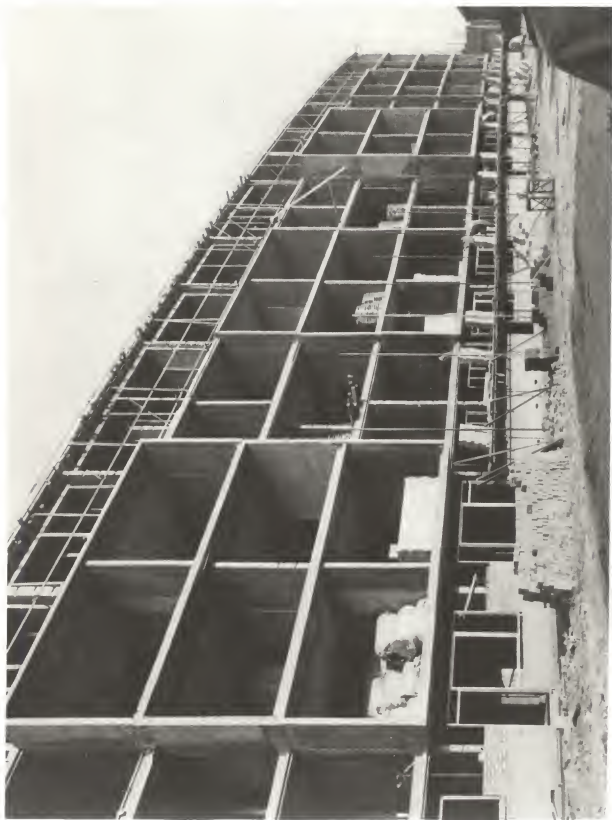
PLATE VI

Apartment Building at Lewisham, London

General view of construction, surface construction as box-frame structure. Note how slabs and walls can be cantilevered.



PLATE VI



## PLATE VII

The Bridge over the Toess near  
Wulfingen, Switzerland

Engineer: Robert Maillart. Note extremely sensitive responses to the natural environment in terms of form and scale; the bridge, an arched reinforced concrete slab forms the main structure. The vertical slabs connect the arch to the platform and parapet walls, which stiffen the arch by resisting all bending moments.

## PLATE VII



PLATE VIII

Exhibition Hall at Turin, Italy

Architect: Pier Luigi Nervi. Note the remarkable way the continuous corrugated arches brought down on to point support.

## PLATE VIII

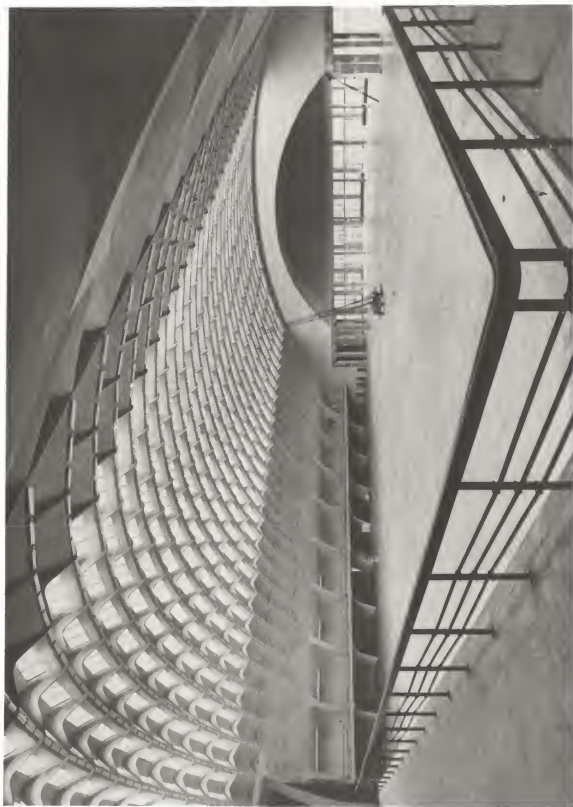


PLATE IX

Virgen Milagrosa, a church

## PLATE IX



PLATE X

Home State Bank, view looking northwest



PLATE X



PLATE XI

Home State Bank, southwest

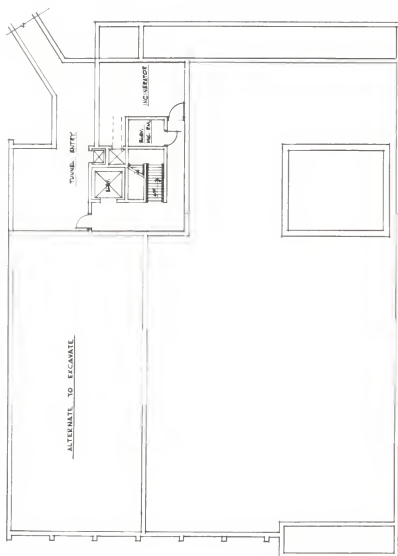
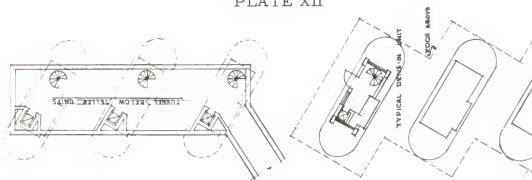
PLATE XI



PLATE XII

Home State Bank, sub-basement plan

PLATE XII



**SUB-BASEMENT PLAN**  
SCALE 1/8" = 1'-0"



PLATE XIII

Home State Bank, ground floor plan



PLATE XIV

Home State Bank, first floor plan





PLATE XV

Home State Bank, second floor plan

PLATE XV

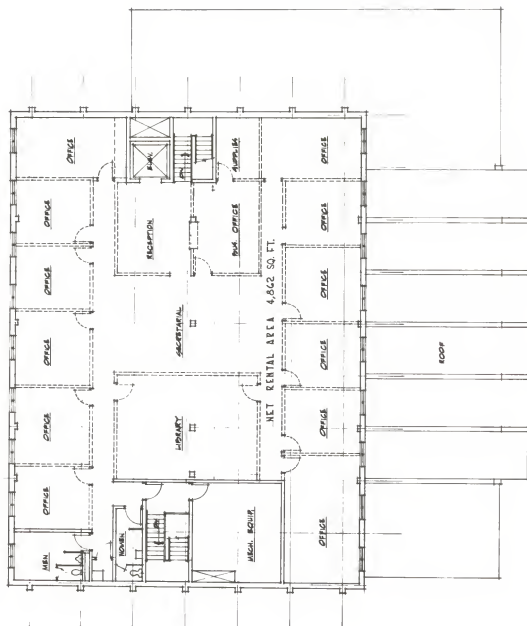
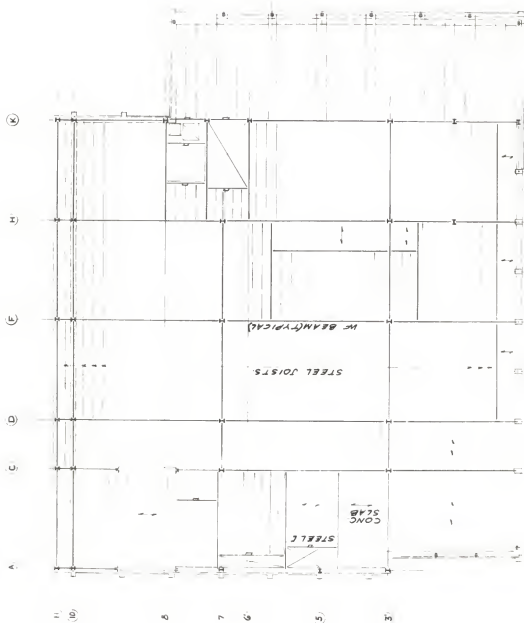
**SECOND FLOOR PLAN**

PLATE XVI

Home State Bank, first floor framing plan

PLATE XVI



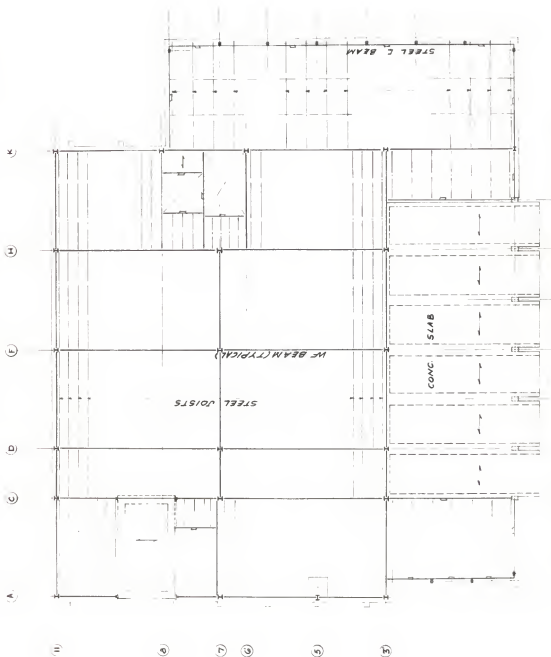
**FIRST FLOOR FRAMING PLAN**

SCALE : 1" = 10' - 0"

PLATE XVII

Home State Bank, second floor framing plan

PLATE XVII



SECOND FLOOR FRAMING PLAN

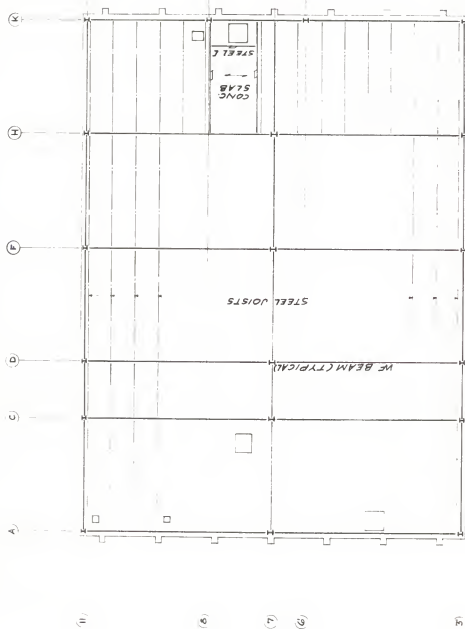
SCALE : 1/4" = 1'-0"

PLATE XVIII

Home State Bank, roof framing plan



## PLATE XVIII



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THE IMPORTANCE OF STRUCTURE  
IN ARCHITECTURAL DESIGN

by

ARUN SAKHARAM DIVADKAR

B. S. , Utah State University, 1960

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AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Architectural Engineering

KANSAS STATE UNIVERSITY  
Manhattan, Kansas

1966

## ABSTRACT

The report deals with the importance of structure in architectural design with a particular emphasis on its relationship to and as a determinant of aesthetic form.

Preliminary and final are two design stages of the architectural design process. The architect puts forth the subjective idea in the preliminary design stage which guides the engineer who works with him. That is why the structural engineer should enter the process after preliminary design stage.

Structure influences the design process through selection of materials and a structural system suitable to the subdivision of the interior spaces.

Some academic check points and general principles, such as structural analysis, its relationship to material, use of geometry of structure, and form suitable to function, should be considered in the design process.

After examining the main purposes of the structure, structural systems are classified according to method of construction and relationship of internal spaces to external forms. They are solid, skeleton and surface constructions.

Critical examination of different functional areas, their vertical and horizontal relationships, pattern of loading, and dimensions of structure, should be used as guiding factors in selection of structural system.

These will produce an honest expression of structure which is architecturally honest, rather than a structure generated by the exterior appearance, where the form may or may not be the outgrowth of functional and structural needs.

These factors and the capacity to feel a structure in an intuitive way as a concept, are then indispensable bases for structural design.

However, balance and harmony, purpose, scale, and structural design consistency are further criteria which add to aesthetic sensitivity of structural form.

Integrated structures (structural functions integrated with architectural form) serves as best examples of aesthetic structural form expression.